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ABSTRACT

Presented are the teacher's guide and student materials for one of a series of self-instructional, computer-based learning modules for an introductory, undergraduate chemistry course. The student module for this heterogeneous ionic equilibria unit includes objectives, prerequisites, pretest, discussion, and 20 problem sets. Included in the teacher's guide are implementation instructions, answers to problem sets, software, computer program in BASIC, and 10 unit tests. (BT)

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CHEMICAL EQUILIBRIUM

UNIT 5. HETEROGENEOUS IONIC EQUILIBRIA

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A COMPUTER-ENRICHED MODULE
FOR INTRODUCTORY CHEMISTRY

$$AgCl_{(s)} \rightleftharpoons Ag^{+}_{(aq)} + Cl^{-}_{(aq)}$$

$$K_{sp} = (Ag^{+})(Cl^{-})$$

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OBJECTIVES

When you finish this module you will be able to

1. use a solubility table and determine whether or not a precipitation reaction will occur.
2. write the net ionic equation for a precipitation reaction.
3. determine the solubility product, K_{sp}, if you have the solubility for a given salt.
4. calculate the solubility for a salt at a given temperature from the solubility product.
5. calculate the effect on the solubility of a salt with the addition of a common ion.
6. understand multiple precipitation reactions.

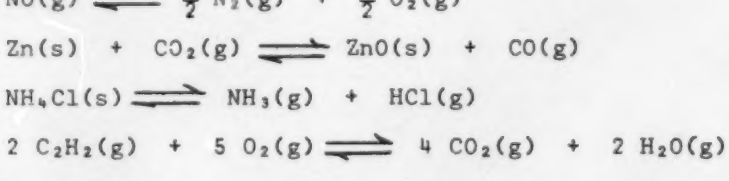
PREREQUISITES

Before you begin this module you should have an understanding of the following concepts:

1. homogeneous equilibria and equilibrium constants.
2. acid-base reactions.
3. Le Chatelier's Principle.

PRE-TEST

1. Write the equilibrium constant expression for each of the following reactions:



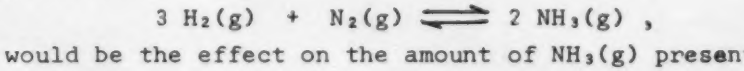
$$NO(g) \rightleftharpoons \tfrac{1}{2} N_2(g) + \tfrac{1}{2} O_2(g)$$

$$Zn(s) + CO_2(g) \rightleftharpoons ZnO(s) + CO(g)$$

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

$$2\ C_2H_2(g) + 5\ O_2(g) \rightleftharpoons 4\ CO_2(g) + 2\ H_2O(g)$$

2. For the reaction



$$3\ H_2(g) + N_2(g) \rightleftharpoons 2\ NH_3(g)\ ,$$

what would be the effect on the amount of $NH_3(g)$ present at equilibrium (a) if additional $H_2(g)$ were introduced, and (b) if the mixture were compressed?

3. For the reaction

$$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g) \qquad (K = 56 \text{ at } 700K)\ ,$$

a mixture is composed of 0.80 moles/l of HI(g) and 0.J2 moles/liter each of $H_2(g)$ and $I_2(g)$ initially.

a. Will there be any net reaction?
b. If so, will HI(g) be consumed or formed?
c. How much HI(g) will exist at equilibrium?

4. For the weak acid, acetic acid, CH_3COOH, the dissociation constant is 1.85×10^{-5} at 25°C.
   a. Calculate the pH and $[H^+]$ for a 0.050 M solution.
   b. Calculate the pH if 0.010 moles of sodium acetate, $NaC_2H_3O_2$, is added to 1.00 liter of the 0.050 M solution. (Neglect volume effects.)

Answers to pre-test:

1. $K = \dfrac{[N_2]^{1/2}[O_2]^{1/2}}{[NO]}$

   $K = \dfrac{[CO]}{[CO_2]}$

   $K = [NH_3][HCl]$

   $K = \dfrac{[CO_2]^4[H_2O]^2}{[O_2]^5[C_2H_2]^2}$

2. (a) increase (b) increase
3. a. yes
   b. consumed
   c. 0.66285 moles/liter
4. a. pH = 3.02, $[H^+] = 9.62 \times 10^{-4}$
   b. pH = 4.03

INTRODUCTION

To begin this module execute the computer program HETERO and evaluate the results shown for the ionic salt, MX(s), dissolved in water.

Use the program, HETERO. What conclusions can you state about these experimental results?

Obviously, at low concentrations the initial amount of the ionic solid dissolves completely in water. The concentrations of the ions in solution show this. However, as the initial concentration of MX(s) in increased, a point is reached where the concentrations of the ions remain constant, regardless of the initial amount of MX(s) added to the system. This is illustrated in the graphic results from HETERO. At this point, the solution is referred to as <u>saturated</u>. The concentration of a salt in a saturated solution is its <u>solubility</u>. It is important to recognize that the system is now at equilibrium. Writing the equilibrium expression for the reaction illustrated in HETERO,

$$K = \frac{[M^+]_{eq}[X^-]_{eq}}{[MX(s)]_{eq}} .$$

However, for a pure solid, the number of moles per liter is proportional to the density of the substance and will remain constant at a constant temperature. As the amount of pure solid decreases, the volume of the solid decreases. For the equilibrium

$$MX(s) \rightleftharpoons M^+(aq) + X^-(aq)$$

the concentration of MX(s) can be included in the equilibrium constant, thus obtaining the expression:

$$K[MX(s)] = K_{sp} = [M^+][X^-] .$$

Such a product of ionic concentrations in a saturated solution is called the solubility product, K_{sp}. Keeping this in mind, write the expressions for the K_{sp} for the following reactions:

Problem 1. $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

$Ag_2CrO_4(s) \rightleftharpoons 2\ Ag^+(aq) + CrO_4^{-2}(aq)$

$PbSO_4(s) \rightleftharpoons Pb^{+2}(aq) + SO_4^{-2}(aq)$

$Al(OH)_3(s) \rightleftharpoons Al^{+3}(aq) + 3\ OH^-(aq)$

The magnitude of the solubility product tells us how soluble a salt is at a given temperature. A salt such as $Ag_2C_2H_3O_2$ is considered soluble, but CuS(s) is not. The solubility product of $Ag_2C_2H_3O_2(s)$ is 2.0×10^{-3}, whereas the solubility product for CuS(s) is very small, 8.5×10^{-36}.

If two solutions of soluble salts are mixed together, and the reaction quotient, the product of <u>initial</u> concentrations of the ions raised to their respective coefficients, is greater than the K_{sp} value, precipitation will occur and solid will form until the product of the corresponding ions is equal to the K_{sp} value. This is simply an application of Le Chatelier's Principle.

Example 1. Two solutions of $AgNO_3$ and NaCl are mixed where the final concentrations of both Ag^+ and Cl^- would be 0.1 M. Therefore, the reaction quotient, Q, would be

$$Q = [Ag^+][Cl^-] = (0.1)(0.1) = 1.0 \times 10^{-2}.$$

Given the K_{sp} for AgCl = 2.0×10^{-10}, we see that $Q > K_{sp}$, so precipitation will occur. Solid AgCl(s) will form until the product, $[Ag^+][Cl^-]$ becomes 2×10^{-10}. At this point the system is at equilibrium.

Since the ions, NO_3^- and Na^+, are not involved in the reaction and do not have a significant role in this reaction, they can be omitted from the discussion. The chemical equation used to illustrate the reaction includes only those ions involved in the reaction and is referred to as the <u>net ionic reaction</u>. Thus, for the example cited the net ionic reaction is

$$Ag^+(aq) + Cl^-(aq) \rightleftharpoons AgCl(s) .$$

There are several very common groups of ions which have very low K_{sp} values, i.e., salts which are relatively insoluble. These salts form precipitates when 0.1 M solutions of the corresponding ions are mixed. These insoluble salts are

listed in TABLE 1. You should be familiar with this table. With the aid of this table you can predict whether or not a reaction will occur when solutions of two soluble salts are mixed.

TABLE 1

NO_3^-	All nitrates are soluble.
Cl^-	All chlorides are soluble except AgCl, Hg_2Cl_2, and $PbCl_2$.
SO_4^{-2}	All sulfates are soluble except $CaSO_4$, $SrSO_4$, $BaSO_4$, Hg_2SO_4, $PbSO_4$, and Ag_2SO_4.
CO_3^{-2}	All carbonates are insoluble except those of the 1A elements and NH_4^+.
OH^-	All hydroxides are insoluble except those of the 1A (alkali metals) elements, $Sr(OH)_2$, and $Ba(OH)_2$. ($Ca(OH)_2$ is slightly soluble.)
S^{-2}	All sulfides are insoluble except those of the 1A (alkali metals) and 2A elements and NH_4^+.

Problem 2. Using TABLE 1, predict whether or not a reaction will occur when 0.1 M solutions of the following ionic salts are mixed. For each example write the net ionic reaction, and if no reaction occurs, indicate by writing N.R.

$NaCl + Ba(OH)_2 \longrightarrow$

$PbNO_3 + KCl \longrightarrow$

$MgS + AlCl_3 \longrightarrow$

$CaS + CuSO_4 \longrightarrow$

$NaNO_3 + BaCl_2 \longrightarrow$

TABLE 2 lists the values for the solubility products of some common salts. You do not need to memorize TABLE 2; however, you will need to refer to it when working some of the problems in the remaining sections of this module. All the information necessary to work the problems in this manual is included in either TABLE 1 or TABLE 2.

The following examples illustrate the types of problems you encounter with heterogeneous equilibria. Note all of these problems are equilibrium problems, and all employ the principles you have learned in the preceding modules.

Example 2. To determine whether or not a solid precipitate will form when given concentrations of the corresponding ions are mixed.

A solution of $AgNO_3$ is mixed with a solution of $NaC_2H_3O_2$ with the final concentrations 0.050 M $AgNO_3$ and 0.10 M $NaC_2H_3O_2$. Given $K_{sp}(AgC_2H_3O_2) = 2 \times 10^{-3}$, will a precipitate of $AgC_2H_3O_2$ form?

$Q = [Ag^+][C_2H_3O_2^-] = (0.05)(0.1) = 5.0 \times 10^{-3}$

We see that $Q > K_{sp}$, therefore a precipitate of $AgC_2H_3O_2$ will form until the product $[Ag^+][C_2H_3O_2^-] = K_{sp}$. At this point the system is at equi-

librium. One can think of this problem as an application of Le Chatelier's Principle.

Example 3. 200 ml of 0.02 M of NaF are mixed with 300 ml of 0.01 M $BaNO_3$. Determine if a precipitate of $BaF_2(s)$ will form ($K_{sp} = 1.7 \times 10^{-6}$).

First, calculate the concentration (in moles/liter) of the F^- and Ba^{+2} ions:

$$F^- \text{ ion: } (0.02\ M)\left(\frac{200\ ml}{500\ ml}\right) = 8.00 \times 10^{-3}\ M$$

$$Ba^{+2} \text{ ion: } (0.01\ M)\left(\frac{300\ ml}{500\ ml}\right) = 6.00 \times 10^{-3}\ M$$

Now, calculate Q:

$$Q = [Ba^{+2}][F^-]^2 = (6.00 \times 10^{-3})(8.00 \times 10^{-3})^2 = 3.84 \times 10^{-7}.$$

Therefore, since $Q < K_{sp}$, a precipitate of $BaF_2(s)$ will not form.

Example 4. To calculate the solubility of a salt given the K_{sp}. The solubility of a salt is the number of grams or moles of the salt which dissolves per liter in a saturated solution. Again, consider the system:

$$AgC_2H_3O_2(s) \rightleftharpoons Ag^+(aq) + C_2H_3O_2^-(aq)$$

Given that $K_{sp} = [Ag^+][C_2H_3O_2^-] = 2 \times 10^{-3}$, how many moles of $AgC_2H_3O_2$ will dissolve in 1 liter of solution?

Set up this equilibrium problem in the form that has been used throughout the equilibrium and acid-base modules.

$$\underset{\text{solid}}{AgC_2H_3O_2(s)} \rightleftharpoons \underset{\text{in solution}}{Ag^+(aq) + C_2H_3O_2^-(aq)}$$

initial amount	A_o moles	0 moles	0 moles
equilibrium amount	$(A_o - y)$ moles	y moles	y moles
concentration in moles/liter	constant	y moles/liter	y moles/liter

A_o is the initial amount of $AgC_2H_3O_2(s)$ and y is defined as the amount of $AgC_2H_3O_2(s)$ in moles/liter which dissolves to form $Ag^+(aq)$ and $C_2H_3O_2^-(aq)$, i.e. the solubility of $AgC_2H_3O_2(s)$.

Wri the K_{sp} expression:

$$K_{sp} = [Ag^+][C_2H_3O_2^-] = 2.0 \times 10^{-3}$$

$$(y)(y) = y^2 = 2.0 \times 10^{-3}$$

$$y = 4.5 \times 10^{-2} \text{ moles/liter.}$$

Example 5. Now, let's consider a more complex example where the coefficients for the ions are not 1:1. For example,

$$Ag_2CrO_4 \rightleftharpoons 2\ Ag^+ + CrO_4^{-2} \qquad K_{sp} = 1 \times 10^{-12}$$

How many moles of $Ag_2CrO_4(s)$ will dissolve in 1 liter of solution?

$$Ag_2CrO_4(s) \rightleftharpoons 2\ Ag^+(aq) + CrO_4^{-2}(aq)$$

initial amount	A_o moles	0 moles	0 moles
equilibrium amount	$(A_o - y)$ moles	2y moles	y moles
concentration in moles/liter	constant	2y moles/liter	y moles/liter

Write the K_{sp} expression, and solve for x, the solubility of $Ag_2CrO_4(s)$ in moles/liter.

$$K_{sp} = [Ag^+]^2[CrO_4^{-2}]$$

Note for every Ag_2CrO_4 molecule that dissolves, two Ag^+ ions are produced.

$$1 \times 10^{-12} = (2y)^2(y) = 4y^3$$

$$y = 6.3 \times 10^{-5} \text{ moles/liter}$$

Note: The most common error is for students to neglect to treat the coefficient 2 correctly.

Consider a problem where you determine the K_{sp} value given the solubility for the salt. This type of problem is exactly like the problem done above. Again, in solving these problems it is advisable to write the equilibrium expression and set up the K_{sp} expression before solving.

Example 6. Calculate the K_{sp} for $CaF_2(s)$, given the solubility of CaF_2 is 3.7×10^{-4} moles/liter.

$$\underset{\text{solid}}{CaF_2(s)} \rightleftharpoons \underset{\text{in solution}}{Ca^{+2}(aq) + 2\ F^-(aq)}$$

initial amount	A_o moles	0 moles	0 moles
equilibrium amount	$(A_o - y)$ moles	y moles	2y moles
concentration in moles/liter	constant	3.7×10^{-4} moles/liter	7.4×10^{-4} moles/liter

y is equal to the solubility of CaF_2 in moles/liter.

Writing the K_{sp} expression:

$$K_{sp} = [Ca^{+2}][F^-]^2 = (3.7 \times 10^{-4})(7.4 \times 10^{-4})^2$$

$$K_{sp} = 2.0 \times 10^{-10}.$$

Listed below are some typical problems to test your mastery of this material.

Problem 3. 200 ml of 0.20 M $Pb(NO_3)_2$ solution are mixed with 300 ml of 0.100 M NaCl.

a. Calculate the number of moles of each ion present before reaction.
b. Write a new ionic equation for the reaction that takes place.
c. Calculate the number of moles of each ion present after reaction.

Problem 4. Write net ionic equations for the reactions, if any, that occur when equal volumes of 0.1 M solutions of the following compounds are mixed. If no reaction occurs, indicate by writing N.R.

a. $KOH + FeCl_2 \longrightarrow$

b. $AgNO_3 + MgCl_2 \longrightarrow$

c. $PbC_2H_3O_2 + K_2SO_4 \longrightarrow$

Problem 5. Given the following solubilities, calculate the corresponding value of K_{sp}.

a. Ag_2S; 3.4×10^{-17} moles/liter

b. $BaCrO_4$; 3.92×10^{-6} grams/ml

c. $Al(OH)_3$; 2.9×10^{-9} moles/liter

Problem 6. A saturated solution of $Mg(OH)_2$ is found to have a pH = 11. Calculate the K_{sp} for $Mg(OH)_2$.

COMMON ION EFFECT

If an equilibrium exists between the ions in solution and the ionic solid, the concentrations of the ions can be changed by adding another salt which has one of the ions in common. This is another example of Le Chatelier's Principle.

For example, suppose the following equilibrium exists:

$$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$$

and NaCl is dissolved in the solution. What effect would this have on the equilibrium? According to Le Chatelier's Principle, the equilibrium would shift to the left reducing the amount of Ag^+ in solution.

Example 7. Let us calculate the $[Ag^+]$ in two solutions, solution A which has 0.1 moles of AgCl added to 1 liter of water and solution B which has the same amount of AgCl and also 0.1 moles of NaCl in the liter of solution.

Solution A: 0.1 M AgCl

$$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$$

$$K_{sp} = [Ag^+][Cl^-] = 1.0 \times 10^{-10}$$

$$[Ag^+] = [Cl^-] = 1.0 \times 10^{-5} \text{ moles/liter.}$$

Solution B: 0.1 M AgCl and 0.1 M NaCl

0.1 M NaCl dissolves completely to give 0.1 M Cl^-

Therefore,

$$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$$

$$\qquad\qquad\quad y \qquad\quad 0.1 + y$$

$$K_{sp} = 1.0 \times 10^{-10} = (y)(0.1 + y).$$

Neglecting the value of y in the term (0.1 + y), gives the result:

$$(y)(0.1) = 1.0 \times 10^{-10}$$

$$y = [Ag^+] = 1.0 \times 10^{-9} \text{ moles/liter.}$$

Note the effect on the Ag^+ concentration. In the solution with the common ion, the concentration of Ag^+ is much lower than in the solution without the common ion. This method of common ion addition is often used to control the concentration of a given ion for particular reactions.

Example 8. Suppose you have a solution which is saturated with $Mg(OH)_2$ ($K_{sp} = 1.2 \times 10^{-11}$). Calculate the amount of $MgCl_2$, which is completely soluble, that you must add to change the pH to 9.0.

Initially, let us calculate the pH of the solution which is saturated with $Mg(OH)_2$. (Hint: Refer to Problem 6)

$$Mg(OH)_2(s) = Mg^{+2}(aq) + 2\ OH^-(aq)$$

$$K_{sp} = 1.2 \times 10^{-11} = (y)(2y)^2 = 4y^3$$

$$y = 1.45 \times 10^{-4}$$

$$[OH^-] = 2.90 \times 10^{-4} \text{ moles/liter}$$

$$[H^+] = 3.42 \times 10^{-11} \text{ moles/liter.}$$

Therefore, pH = 11.

However, for a pH of 9.0,

$$[H^+] = 1.0 \times 10^{-9} \text{ moles/liter}$$

$$[OH^-] = 1.0 \times 10^{-5} \text{ moles/liter}$$

and therefore,

$$K_{sp} = [Mg^{+2}](1.0 \times 10^{-5})^2 = 1.2 \times 10^{-11}$$

$$[Mg^{+2}] = 0.12 \text{ moles/liter.}$$

The amount of $MgCl_2$ that must be added to change the pH to 9.0 is 0.12 moles/liter.

Example 9. The final type of problem to be considered in this module is one in which two precipitates may form and we wish to decide which ion will precipitate first. Suppose a solution consists of 0.1 M Na_2CrO_4 and 0.1 M NaCl and Ag^+ is slowly added to the system. Determine which solid will form first, $Ag_2CrO_4(s)$ or AgCl(s).

You solve this type of problem by calculating the Ag^+ concentration required for precipitation to occur in each case.

AgCl: $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

$$K_{sp} = [Ag^+][Cl^-]$$

$$1.0 \times 10^{-10} = [Ag^+](0.1)$$

$$[Ag^+] = 1.0 \times 10^{-9} \text{ moles/liter}$$

i.e. when $[Ag^+]$ exceeds 1.0×10^{-9} moles/liter, AgCl(s) will precipitate.

Ag_2CrO_4: $Ag_2CrO_4(s) \rightleftharpoons 2\ Ag^+(aq) + CrO_4^{-2}(aq)$

$$K_{sp} = [Ag^+]^2[CrO_4^{-2}]$$

$$1.2 \times 10^{-12} = [Ag^+]^2(0.1)$$

$$[Ag^+]^2 = 1.2 \times 10^{-11}$$

$[Ag^+] = 3.5 \times 10^{-6}$ moles/liter

i.e. when $[Ag^+]$ exceeds 3.5×10^{-6} moles/liter, $Ag_2CrO_4(s)$ will precipitate.

Since 1.0×10^{-9} is less than 3.5×10^{-6}, AgCl(s) will precipitate first.

TABLE 2: Solubility Products of Salts.

Fluorides		Chromates		Sulfides	
$[Ba^{++}][F^-]^2$	$= 1.7\times10^{-6}$	$[Ba^{++}][CrO_4^=]$	$= 2.4\times10^{-10}$	$[Zn^{++}][S^=]$	$= 1 \times10^{-23}$
$[Ca^{++}][F^-]^2$	$= 3.4\times10^{-11}$	$[Pb^{++}][CrO_4^=]$	$= 1.8\times10^{-14}$	$[Cd^{++}][S^=]$	$= 8 \times10^{-27}$
$[Mg^{++}][F^-]^2$	$= 6.5\times10^{-9}$	$[Ag^+]^2[CrO_4^=]$	$= 1.2\times10^{-12}$	$[Hg^{++}][S^=]$	$= 2 \times10^{-52}$
$[Pb^{++}][F^-]^2$	$= 3.6\times10^{-8}$	Sulfates		$[Cu^{++}][S^=]$	$= 8.5\times10^{-36}$
Chlorides		$[Ba^{++}][SO_4^=]$	$= 1 \times10^{-10}$	$[Ni^{++}][S^=]$	$= 2 \times10^{-21}$
$[Ag^+][Cl^-]$	$= 1 \times10^{-10}$	$[Sr^{++}][SO_4^=]$	$= 2.8\times10^{-7}$	$[Co^{++}][S^=]$	$= 8 \times10^{-22}$
$[Cu^+][Cl^-]$	$= 1.0\times10^{-6}$	$[Ca^{++}][SO_4^=]$	$= 2 \times10^{-4}$	$[Fe^{++}][S^=]$	$= 3.7\times10^{-18}$
$[Hg_2^{++}][Cl^-]^2$	$= 2.0\times10^{-18}$	$[Pb^{++}][SO_4^=]$	$= 2 \times10^{-8}$	$[Mn^{++}][S^=]$	$= 2.5\times10^{-10}$
$[Pb^{++}][Cl^-]^2$	$= 1.7\times10^{-5}$	Hydroxides		$[Ag^+]^2[S^=]$	$= 1.6\times10^{-49}$
Iodides		$[Al^{3+}][OH^-]^3$	$= 2 \times10^{-33}$	Carbonates	
$[Ag^+][I^-]$	$= 1.5\times10^{-16}$	$[Mg^{++}][OH^-]^2$	$= 1.2\times10^{-11}$	$[Ba^{++}][CO_3^=]$	$= 5 \times10^{-9}$
$[Cu^+][I^-]$	$= 5 \times10^{-12}$	$[Fe^{3+}][OH^-]^3$	$= 1.1\times10^{-36}$	$[Ca^{++}][CO_3^=]$	$= 1 \times10^{-8}$
$[Hg_2^{++}][I^-]^2$	$= 1.2\times10^{-28}$	$[Mn^{++}][OH^-]^2$	$= 4 \times10^{-14}$	$[Mg^{++}][CO_3^=]$	$= 2.6\times10^{-5}$
$[Pb^{++}][I^-]^2$	$= 1.4\times10^{-8}$	$[Ni^{++}][OH^-]^2$	$= 4 \times10^{-14}$	$[Pb^{++}][CO_3^=]$	$= 3.3\times10^{-14}$
		$[Cu^{++}][OH^-]^2$	$= 1 \times10^{-19}$		
		$[Zn^{++}][OH^-]^2$	$= 1.8\times10^{-14}$		
		$[Fe^{++}][OH^-]^2$	$= 1.6\times10^{-14}$		

Problem Set 1

1. WHEN 44 ML OF 0.2440 M Pb^{+2} IS ADDED TO 56 ML OF 0.2740 M CO_3^{-2} HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF $PbCO_3$ IS 1.50E-15 .

2. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF AgI IN A SOLUTION THAT CONTAINS A TOTAL OF 0.532 MOLE/LITER OF Ag^{+1} ?
   THE Ksp OF AgI IS 8.50E-17 .

3. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF PbC_2O_4 IN WATER?
   THE Ksp OF PbC_2O_4 IS 8.30E-12 .

4. A SOLUTION IS 0.682 M IN CO_3^{-2} AND 0.9700 M IN Br^{-1} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbCO_3$ OR $PbBr_2$?
   THE Ksp OF $PbCO_3$ IS 1.50E-15. THE Ksp OF $PbBr_2$ IS 4.60E-06.
   AND WHAT WILL BE THE CONCENTRATION OF THE CO_3^{-2} ION WHEN $PbBr_2$ BEGINS TO PRECIPITATE?

Problem Set 2

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF PbC_2O_4 IN A SOLUTION THAT CONTAINS A TOTAL OF 0.168 MOLE/LITER OF Pb^{+2} ?
   THE Ksp OF PbC_2O_4 IS 8.30E-12 .

2. THE Ksp OF PbS IS 7.00E-29 .
   WHAT IS THE SOLUBILITY OF PbS IN WATER IN G/ML ?

3. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.713 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH Cl^{-1} IS ADDED TO MAKE Cl^{-1} CONCENTRATION 0.187 MOLAR?
   THE Ksp OF $PbCl_2$ IS 1.60E-05 .
   WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

4. A SOLUTION IS 0.192 M IN CO_3^{-2} AND 0.4400 M IN Br^{-1} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, Ag_2CO_3 OR AgBr ?
   THE Ksp OF Ag_2CO_3 IS 8.20E-12. THE Ksp OF AgBr IS 5.00E-13.
   AND WHAT WILL BE THE CONCENTRATION OF THE Br^{-1} ION WHEN Ag_2CO_3 BEGINS TO PRECIPITATE?

Problem Set 3

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF PbI_2 IN A SOLUTION THAT CONTAINS A TOTAL OF 0.580 MOLE/LITER OF Pb^{+2} ?
   THE Ksp OF PbI_2 IS 8.30E-09 .

2. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Ag^{+1} IS 0.727 MOLAR. IF IT IS DESIRED TO REMOVE 41.405 % OF Ag^{+1} BY ADDING $C_2O_4^{-2}$, WHAT MUST $(C_2O_4^{-2})$ BE?
   THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .

3. A SOLUTION IS 0.870 M IN Cl^{-1} AND 0.9221 M IN S^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, AgCl OR Ag_2S ?
   THE Ksp OF AgCl IS 1.70E-10. THE Ksp OF Ag_2S IS 5.50E-51.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN AgCl BEGINS TO PRECIPITATE?

4. THE SOLUBILITY OF PbI_2 IN WATER IS 5.88E-01 G/L.
   CALCULATE THE Ksp OF PbI_2.

Problem Set 4

1. WHEN 14 ML OF 0.4411 M Ca^{+2} IS ADDED TO 86 ML OF 0.7610 M CO_3^{-2}
   HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF $CaCO_3$ IS 2.50E-10 .

2. A SOLUTION IS 0.481 M IN Br^{-1} AND 0.1490 M IN Cl^{-1} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbBr_2$ OR $PbCl_2$?
   THE Ksp OF $PbBr_2$ IS 4.60E-06. THE Ksp OF $PbCl_2$ IS 1.60E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE Br^{-1} ION WHEN $PbCl_2$ BEGINS TO PRECIPITATE?

3. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF AgI IN WATER?
   THE Ksp OF AgI IS 8.50E-17 .

4. THE Ksp OF Ag_2S IS 5.50E-51 .
   WHAT WILL THE RESULTING Ag^{+1} CONCENTRATION BE IF ENOUGH S^{-2} IS ADDED TO A SATURATED SOLUTION OF Ag_2S TO MAKE (S^{-2}) 0.244 MOLAR?

Problem Set 5

1. A SOLUTION IS 0.907 M IN $C_2O_4^{-2}$ AND 0.4431 M IN SO_4^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $Ag_2C_2O_4$ OR Ag_2SO_4 ?
   THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11. THE Ksp OF Ag_2SO_4 IS 1.20E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE $C_2O_4^{-2}$ ION WHEN Ag_2SO_4
   BEGINS TO PRECIPITATE?

2. THE Ksp OF Ag_2SO_4 IS 1.20E-05 .
   WHAT IS THE SOLUBILITY OF Ag_2SO_4 IN WATER IN G/ML ?

3. THE Ksp OF AgBr IS 5.00E-13 .
   WHAT WILL THE RESULTING Ag^{+1} CONCENTRATION BE IF ENOUGH
   Br^{-1} IS ADDED TO A SATURATED SOLUTION OF AgBr
   TO MAKE (Br^{-1}) 0.406 MOLAR?

4. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Ag^{+1} IS 0.720 MOLAR.
   IF IT IS DESIRED TO REMOVE 96.106 % OF Ag^{+1}
   BY ADDING Cl^{-1}, WHAT MUST (Cl^{-1}) BE?
   THE Ksp OF AgCl IS 1.70E-10 .

Problem Set 6

1. A SOLUTION IS 0.648 M IN S^{-2} AND 0.9641 M IN CrO_4^{-2} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, PbS OR $PbCrO_4$?
   THE Ksp OF PbS IS 7.00E-29. THE Ksp OF $PbCrO_4$ IS 2.00E-16.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN $PbCrO_4$
   BEGINS TO PRECIPITATE?

2. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF
   $PbCO_3$ IN WATER?
   THE Ksp OF $PbCO_3$ IS 1.50E-15 .

3. THE Ksp OF PbI_2 IS 8.30E-09 .
   WHAT WILL THE RESULTING Pb^{+2} CONCENTRATION BE IF ENOUGH
   I^{-1} IS ADDED TO A SATURATED SOLUTION OF PbI_2
   TO MAKE (I^{-1}) 0.291 MOLAR?

4. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.100 MOLAR.
   IF IT IS DESIRED TO REMOVE 33.806 % OF Pb^{+2}
   BY ADDING Br^{-1}, WHAT MUST (Br^{-1}) BE?
   THE Ksp OF $PbBr_2$ IS 4.60E-06 .

Problem Set 7

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF AgBr IN A SOLUTION THAT CONTAINS A TOTAL OF 0.394 MOLE/LITER OF Ag^{+1} ?
   THE Ksp OF AgBr IS 5.00E-13 .

2. IF A SOLUTION CONTAINING 0.976 MOLE/LITER OF Pb^{+2} IS MADE 9.11E-29 MOLAR IN S^{-2} ION, WHAT % OF THE Pb^{+2} IS REMOVED AS PbS ?
   THE Ksp OF PbS IS 7.00E-29 .

3. A SOLUTION IS 0.308 M IN Cl^{-1} AND 0.2371 M IN CrO_4^{-2} . IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, AgCl OR Ag_2CrO_4 ?
   THE Ksp OF AgCl IS 1.70E-10. THE Ksp OF Ag_2CrO_4 IS 1.90E-12. AND WHAT WILL BE THE CONCENTRATION OF THE Cl^{-1} ION WHEN Ag_2CrO_4 BEGINS TO PRECIPITATE?

4. THE SOLUBILITY OF SrF_2 IN WATER IS 7.31E-02 G/L. CALCULATE THE Ksp OF SrF_2.

Problem Set 8

1. A SOLUTION IS 0.245 M IN SO_4^{-2} AND 0.2281 M IN Cl^{-1} . IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbSO_4$ OR $PbCl_2$?
   THE Ksp OF $PbSO_4$ IS 1.30E-08. THE Ksp OF $PbCl_2$ IS 1.60E-05. AND WHAT WILL BE THE CONCENTRATION OF THE SO_4^{-2} ION WHEN $PbCl_2$ BEGINS TO PRECIPITATE?

2. THE Ksp OF Ag_2CO_3 IS 8.20E-12 .
   WHAT WILL THE RESULTING Ag^{+1} CONCENTRATION BE IF ENOUGH CO_3^{-2} IS ADDED TO A SATURATED SOLUTION OF Ag_2CO_3 TO MAKE (CO_3^{-2}) 0.083 MOLAR?

3. IF A SOLUTION CONTAINING 0.865 MOLE/LITER OF Sr^{+2} IS MADE 1.20E-04 MOLAR IN F^{-1} ION, WHAT % OF THE Sr^{+2} IS REMOVED AS SrF_2 ?
   THE Ksp OF SrF_2 IS 7.90E-10 .

4. THE SOLUBILITY OF Hg_2CrO_4 IN WATER IS 4.11E-01 G/L. CALCULATE THE Ksp OF Hg_2CrO_4.

Problem Set 9

1. A SOLUTION IS 0.546 M IN CrO_4^{-2} AND 0.3911 M IN SO_4^{-2} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $PbCrO_4$ OR $PbSO_4$?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16. THE Ksp OF $PbSO_4$ IS 1.30E-08.
   AND WHAT WILL BE THE CONCENTRATION OF THE CrO_4^{-2} ION WHEN $PbSO_4$
   BEGINS TO PRECIPITATE?

2. IF Co^{+2} IS SLOWLY ADDED TO A SOLUTION
   0.767 MOLAR IN S^{-2} , AT WHAT CONCENTRATION OF Co^{+2}
   DOES A PRECIPITATE START TO FORM?
   THE Ksp OF CoS IS 5.00E-22 .

3. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.993 MOLAR.
   IF IT IS DESIRED TO REMOVE 14.406 % OF Pb^{+2}
   BY ADDING SO_4^{-2}, WHAT MUST (SO_4^{-2}) BE?
   THE Ksp OF $PbSO_4$ IS 1.30E-08 .

4. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF
   AgI IN WATER?
   THE Ksp OF AgI IS 8.50E-17 .

Problem Set 10

1. THE Ksp OF SrF_2 IS 7.90E-10 .
   WHAT WILL THE RESULTING Sr^{+2} CONCENTRATION BE IF ENOUGH
   F^{-1} IS ADDED TO A SATURATED SOLUTION OF SrF_2
   TO MAKE (F^{-1}) 0.381 MOLAR?

2. THE Ksp OF CuS IS 8.00E-37 .
   WHAT IS THE SOLUBILITY OF CuS IN WATER IN G/ML ?

3. IF THE Co^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY
   0.653 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH S^{-2} IS ADDED
   TO MAKE S^{-2} CONCENTRATION 0.539 MOLAR?
   THE Ksp OF CoS IS 5.00E-22 .
   WHAT IS THE RESULTING CONCENTRATION OF Co^{+2} ?

4. A SOLUTION IS 0.909 M IN I^{-1} AND 0.9230 M IN Cl^{-1} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, PbI_2 OR $PbCl_2$?
   THE Ksp OF PbI_2 IS 8.30E-09. THE Ksp OF $PbCl_2$ IS 1.60E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE I^{-1} ION WHEN $PbCl_2$
   BEGINS TO PRECIPITATE?

Problem Set 11

1. A SOLUTION IS 0.957 M IN Br^{-1} AND 0.6040 M IN CrO_4^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, AgBr OR Ag_2CrO_4 ?
   THE Ksp OF AgBr IS 5.00E-13. THE Ksp OF Ag_2CrO_4 IS 1.90E-12.
   AND WHAT WILL BE THE CONCENTRATION OF THE Br^{-1} ION WHEN Ag_2CrO_4
   BEGINS TO PRECIPITATE?

2. IF THE Cu^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY
   0.083 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH S^{-2} IS ADDED
   TO MAKE S^{-2} CONCENTRATION 0.746 MOLAR?
   THE Ksp OF CuS IS 8.00E-37 .
   WHAT IS THE RESULTING CONCENTRATION OF Cu^{+2} ?

3. THE Ksp OF $PbCl_2$ IS 1.60E-05 .
   WHAT WILL THE RESULTING Pb^{+2} CONCENTRATION BE IF ENOUGH
   Cl^{-1} IS ADDED TO A SATURATED SOLUTION OF $PbCl_2$
   TO MAKE (Cl^{-1}) 0.224 MOLAR?

4. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF
   $PbCO_3$ IN WATER?
   THE Ksp OF $PbCO_3$ IS 1.50E-15 .

Problem Set 12

1. A SOLUTION IS 0.781 M IN SO_4^{-2} AND 0.5771 M IN CO_3^{-2} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $PbSO_4$ OR $PbCO_3$?
   THE Ksp OF $PbSO_4$ IS 1.30E-08. THE Ksp OF $PbCO_3$ IS 1.50E-15.
   AND WHAT WILL BE THE CONCENTRATION OF THE CO_3^{-2} ION WHEN $PbSO_4$
   BEGINS TO PRECIPITATE?

2. IF Ag^{+1} IS SLOWLY ADDED TO A SOLUTION
   0.165 MOLAR IN I^{-1} , AT WHAT CONCENTRATION OF Ag^{+1}
   DOES A PRECIPITATE START TO FORM?
   THE Ksp OF AgI IS 8.50E-17 .

3. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Ag^{+1} IS 0.549 MOLAR.
   IF IT IS DESIRED TO REMOVE 72.005 % OF Ag^{+1}
   BY ADDING Br^{-1}, WHAT MUST (Br^{-1}) BE?
   THE Ksp OF AgBr IS 5.00E-13 .

4. THE Ksp OF Ag_2CO_3 IS 8.20E-12 .
   WHAT IS THE SOLUBILITY OF Ag_2CO_3 IN WATER IN G/ML ?

Problem Set 13

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF Ag_2CO_3 IN A SOLUTION THAT CONTAINS A TOTAL OF 0.227 MOLE/LITER OF Ag^{+1} ?
   THE Ksp OF Ag_2CO_3 IS 8.20E-12 .

2. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Co^{+2} IS 0.734 MOLAR. IF IT IS DESIRED TO REMOVE 20.605 % OF Co^{+2} BY ADDING S^{-2}, WHAT MUST (S^{-2}) BE?
   THE Ksp OF CoS IS 5.00E-22 .

3. A SOLUTION IS 0.272 M IN S^{-2} AND 0.5780 M IN CrO_4^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, Ag_2S OR Ag_2CrO_4 ?
   THE Ksp OF Ag_2S IS 5.50E-51. THE Ksp OF Ag_2CrO_4 IS 1.90E-12.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN Ag_2CrO_4 BEGINS TO PRECIPITATE?

4. THE SOLUBILITY OF $PbCO_3$ IN WATER IS 1.03E-05 G/L.
   CALCULATE THE Ksp OF $PbCO_3$.

Problem Set 14

1. A SOLUTION IS 0.690 M IN Br^{-1} AND 0.1761 M IN $C_2O_4^{-2}$.
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, AgBr OR $Ag_2C_2O_4$?
   THE Ksp OF AgBr IS 5.00E-13. THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11.
   AND WHAT WILL BE THE CONCENTRATION OF THE Br^{-1} ION WHEN $Ag_2C_2O_4$ BEGINS TO PRECIPITATE?

2. IF Sr^{+2} IS SLOWLY ADDED TO A SOLUTION 0.667 MOLAR IN SO_4^{-2} , AT WHAT CONCENTRATION OF Sr^{+2} DOES A PRECIPITATE START TO FORM?
   THE Ksp OF $SrSO_4$ IS 7.60E-07 .

3. THE Ksp OF AgBr IS 5.00E-13 .
   WHAT IS THE SOLUBILITY OF AgBr IN WATER IN G/ML ?

4. WHEN 27 ML OF 0.9461 M Pb^{+2} IS ADDED TO 73 ML OF 0.6490 M $C_2O_4^{-2}$ HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF PbC_2O_4 IS 8.30E-12 .

Problem Set 15

1. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.537 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH CrO_4^{-2} IS ADDED TO MAKE CrO_4^{-2} CONCENTRATION 0.694 MOLAR?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16 .
   WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

2. THE SOLUBILITY OF PbS IN WATER IS 2.00E-12 G/L.
   CALCULATE THE Ksp OF PbS.

3. A SOLUTION IS 0.972 M IN $C_2O_4^{-2}$ AND 0.0820 M IN CrO_4^{-2} .
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, PbC_2O_4 OR $PbCrO_4$?
   THE Ksp OF PbC_2O_4 IS 8.30E-12. THE Ksp OF $PbCrO_4$ IS 2.00E-16.
   AND WHAT WILL BE THE CONCENTRATION OF THE CrO_4^{-2} ION WHEN PbC_2O_4 BEGINS TO PRECIPITATE?

4. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $BaCrO_4$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.170 MOLE/LITER OF Ba^{+2} ?
   THE Ksp OF $BaCrO_4$ IS 8.50E-11 .

Problem Set 16

1. A SOLUTION IS 0.880 M IN CO_3^{-2} AND 0.8631 M IN S^{-2} .
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbCO_3$ OR PbS ?
   THE Ksp OF $PbCO_3$ IS 1.50E-15. THE Ksp OF PbS IS 7.00E-29.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN $PbCO_3$ BEGINS TO PRECIPITATE?

2. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF SrF_2 IN A SOLUTION THAT CONTAINS A TOTAL OF 0.096 MOLE/LITER OF Sr^{+2} ?
   THE Ksp OF SrF_2 IS 7.90E-10 .

3. IF A SOLUTION CONTAINING 0.141 MOLE/LITER OF Sr^{+2} IS MADE 1.06E-04 MOLAR IN F^{-1} ION, WHAT % OF THE Sr^{+2} IS REMOVED AS SrF_2 ?
   THE Ksp OF SrF_2 IS 7.90E-10 .

4. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF AgBr IN WATER?
   THE Ksp OF AgBr IS 5.00E-13 .

Problem Set 17

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF CoS IN A SOLUTION THAT CONTAINS A TOTAL OF 0.769 MOLE/LITER OF Co^{+2} ?
   THE Ksp OF CoS IS 5.00E-22 .

2. THE Ksp OF $PbBr_2$ IS 4.60E-06
   WHAT IS THE SOLUBILITY OF $PbBr_2$ IN WATER IN G/ML ?

3. A SOLUTION IS 0.291 M IN Br^{-1} AND 0.0041 M IN CrO_4^{-2} .
   IF SOLID $Pb(NO_3)_2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbBr_2$ OR $PbCrO_4$?
   THE Ksp OF $PbBr_2$ IS 4.60E-06. THE Ksp OF $PbCrO_4$ IS 2.00E-16.
   AND WHAT WILL BE THE CONCENTRATION OF THE CrO_4^{-2} ION WHEN $PbBr_2$ BEGINS TO PRECIPITATE?

4. IF A SOLUTION CONTAINING 0.373 MOLE/LITER OF Ag^{+1} IS MADE 1.47E-08 MOLAR IN Cl^{-1} ION, WHAT % OF THE Ag^{+1} IS REMOVED AS AgCl ?
   THE Ksp OF AgCl IS 1.70E-10 .

Problem Set 18

1. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Ag^{+1} IS 0.448 MOLAR. IF IT IS DESIRED TO REMOVE 69.705 % OF Ag^{+1} BY ADDING S^{-2}, WHAT MUST (S^{-2}) BE?
   THE Ksp OF Ag_2S IS 5.50E-51 .

2. THE SOLUBILITY OF Ag_2CrO_4 IN WATER IS 4.11E-01 G/L. CALCULATE THE Ksp OF Ag_2CrO_4.

3. A SOLUTION IS 0.944 M IN S^{-2} AND 0.5051 M IN SO_4^{-2} .
   IF SOLID $AgNO_3$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, Ag_2S OR Ag_2SO_4 ?
   THE Ksp OF Ag_2S IS 5.50E-51. THE Ksp OF Ag_2SO_4 IS 1.20E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN Ag_2SO_4 BEGINS TO PRECIPITATE?

4. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $BaCO_3$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.196 MOLE/LITER OF Ba^{+2} ?
   THE Ksp OF $BaCO_3$ IS 1.60E-09 .

Problem Set 19

1. A SOLUTION IS 0.943 M IN I^{-1} AND 0.1941 M IN CrO_4^{-2} .
IF SOLID $AgNO_3$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
WILL PRECIPITATE FIRST, AgI OR Ag_2CrO_4 ?
THE Ksp OF AgI IS 8.5E-17. THE Ksp OF Ag_2CrO_4 IS 1.9E-12.
AND WHAT WILL BE THE CONCENTRATION OF THE I^{-1} ION WHEN Ag_2CrO_4
BEGINS TO PRECIPITATE?

2. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY
0.094 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH I^{-1} IS ADDED
TO MAKE I^{-1} CONCENTRATION 0.428 MOLAR?
THE Ksp OF PbI_2 IS 8.3E-09 .
WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

3. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF CaF_2 IN
A SOLUTION THAT CONTAINS A TOTAL OF 0.918 MOLE/LITER OF
Ca^{+2} ?
THE Ksp OF CaF_2 IS 3.5OE-11 .

4. THE Ksp OF PbI_2 IS 8.3OE-09 .
WHAT IS THE SOLUBILITY OF PbI_2 IN WATER IN G/ML ?

1. A SOLUTION IS 0.482 M IN Cl^{-1} AND 0.8501 M IN $C_2O_4^{-2}$.
IF SOLID $Pb(NO_3)_2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
WILL PRECIPITATE FIRST, $PbCl_2$ OR PbC_2O_4 ?
THE Ksp OF $PbCl_2$ IS 1.6OE-05. THE Ksp OF PbC_2O_4 IS 8.3OE-12.
AND WHAT WILL BE THE CONCENTRATION OF THE $C_2O_4^{-2}$ ION WHEN $PbCl_2$
BEGINS TO PRECIPITATE?

2. IF A SOLUTION CONTAINING 0.821 MOLE/LITER OF
Ba^{+2} IS MADE 2.41E-09 MOLAR IN SO_4^{-2} ION,
WHAT % OF THE Ba^{+2} IS REMOVED AS $BaSO_4$?
THE Ksp OF $BaSO_4$ IS 1.5OE-09 .

3. IF Pb^{+2} IS SLOWLY ADDED TO A SOLUTION
0.769 MOLAR IN CrO_4^{-2} , AT WHAT CONCENTRATION OF Pb^{+2}
DOES A PRECIPITATE START TO FORM?
THE Ksp OF $PbCrO_4$ IS 2.00E-16 .

4. WHAT IS THE Ba^{+2} CONCENTRATION IN A SATURATED SOLUTION OF
$BaCrO_4$ IN WATER?
THE Ksp OF $BaCrO_4$ IS 8.5OE-11 .

The CM Project

The Computer-enriched Module (CM) project is a collaborative effort by 19 faculty members in the disciplines of chemistry, mathematics and physics, to produce self-instructional computer-based materials at the introductory college level in those disciplines. Each module is designed to be usable in an academic environment with minimal computational facilities, and by students and faculty who are not programming experts. It may be used as an adjunct to standard textual materials, or in many cases, as a replacement for them. The primary aim of each module is to use the computer in such a way that students may take a more active role in the development and discovery of concepts and phenomena.

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TEACHER'S GUIDE TO

A MODULE ON CHEMICAL EQUILIBRIUM

UNIT 5. HETEROGENEOUS IONIC EQUILIBRIA

JOHN J. MANOCK

WESTERN CAROLINA UNIVERSITY

a computer-enriched module

for introductory chemistry

featuring the program

HETERO

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TEACHER'S GUIDE TO UNIT ON HETEROGENEOUS IONIC EQUILIBRIA OF THE CHEMICAL EQUILIBRIUM MODULE

EDUCATIONAL OBJECTIVES

When a student has completed this unit he should understand the principles of heterogeneous ionic equilibria and be able to (1) write net ionic reactions, (2) solve problems involving K_{sp} and solubility, and (3) solve quantitative problems involving common ions and multiple equilibria. The intent of this module is to show the student that heterogeneous equilibria are not unique, but are the same as the other forms of equilibria he has previously encountered. The selection of problems is designed to build on the student's knowledge of homogeneous and acid-base equilibria.

IMPLEMENTATION

The module begins with the computer program HETERO which produces simulated data for the system

$$MX(s) = M^{+}(aq) + X^{-}(aq) .$$

As additional amounts of MX(s) are added to the system, the simulated experimental data are tabulated and shown graphically. The object of this computer program is to illustrate to the student the lack of dependence on the amount of MX(s) added after the system has achieved equilibrium. It is imperative that the student use the computer program HETERO prior to any classroom discussion on heterogeneous equilibria. Otherwise, the discovery of the concept of heterogeneous equilibria by the inquiry approach is lost, and the program serves no purpose.

Following the qualitative introduction, quantitative problems of increasing difficulty are presented to the student. This unit may either be used as augmentation to the lecture material, by itself or with the other units in the chemical equilibrium module. The time required for the completion of this module will vary depending upon the student's ability to solve quantitative problems. The time required to execute the computer program HETERO will be approximately five minutes.

ANSWERS TO PROBLEM SETS

TEST 1	TEST 2	TEST 3
1. 1.07E-02	1. 4.94E-11	1. 5.98E-05
2. 1.60E-16	2. 2.00E-15	2. 6.06E-11 M
3. 2.88E-06 M	3. YES 4.57E-04 M	3. Ag_2S 1.44E-31
4. $PbCO_3$ 3.07E-10	4. AgBr 7.65E-08	4. 8.30E-09

TEST 4	TEST 5	TEST 6
1. 6.17E-03	1. $Ag_2C_2O_4$ 4.06E-07	1. PbS 3.37E-13
2. $PbBr_2$ 7.99E-02	2. 4.50E-03	2. 3.87E-08 M
3. 9.22E-09 M	3. 1.23E-12 M	3. 9.80E-08 M
4. 1.50E-25 M	4. 6.06E-09 M	4. 8.34E-03 M

TEST 7

1. 1.27E-12

2. 2.13E+01

3. AgCl 6.00E-05

4. 7.90E-10

TEST 8

1. $PbSO_4$ 4.23E-05

2. 9.94E-06 M

3. 9.37E+01

4. 2.00E-09

TEST 9

1. $PbCrO_4$ 6.02E-09

2. 6.52E-22 M

3. 1.53E-08 M

4. 9.22E-09 M

TEST 10

1. 5.44E-09 M

2. 8.54E-20

3. YES 9.28E-22 M

4. PbI_2 2.10E-02

TEST 11

1. AgBr 2.82E-07

2. YES 1.07E-36 M

3. 3.19E-04 M

4. 3.87E-08 M

TEST 12

1. $PbCO_3$ 9.01E-08

2. 5.15E-16 M

3. 3.25E-12 M

4. 3.50E-05

TEST 13

1. 1.59E-10
2. 8.58E-22 M
3. Ag_2S 1.67E-39
4. 1.50E-15

TEST 14

1. AgBr 6.33E-08
2. 1.14E-06 M
3. 1.33E-07
4. 2.55E-02

TEST 15

1. YES 2.88E-16 M
2. 7.00E-29
3. $PbCrO_4$ 2.34E-05
4. 5.00E-10

TEST 16

1. PbS 4.11E-14
2. 4.54E-05
3. 5.04E+01
4. 7.07E-07 M

TEST 17

1. 6.50E-22
2. 3.85E-03
3. $PbCrO_4$ 3.68E-12
4. 9.69E+01

TEST 18

1. 2.99E-49 M
2. 2.00E-09
3. Ag_2S 2.31E-46
4. 8.16E-09

TEST 19

1. AgI 2.65E-11

2. YES 4.53E-08 M

3. 3.09E-06

4. 5.88E-04

TEST 20

1. PbC_2O_4 1.21E-07

2. 9.21E+00

3. 2.60E-16 M

4. 9.22E-06 M

SOFTWARE

HETERO is written with the intent that a student receive his data from a terminal in an interactive mode. With the tabulated data the student should feel that this is real experimental data being recorded. The graphical display illustrates to the freshman student the importance of graphing data. HETERO can easily be used in a batch mode, however, the effect of the simulated experiment will be lost. The BASIC listing of the program is shown along with the output data.

Sample run of HETERO

```
 RESULTS TO ILLUSTRATE THE HETEROGENEOUS SYSTEM

                MX(S)      =  M(AQ)  +  X(AQ)

AS IT ACHIEVES EQUILIBRIUM WITH THE ADDITION OF
 MORE MX(S) TO THE SYSTEM.  LISTED BELOW ARE
THE TABULAR RESULTS AND THE GRAPHICAL RESULTS. HOW
WOULD YOU INTERPRET THE RESULTS FROM YOUR KNOWLEDGE OF
EQUILIBRIA SYSTEMS?
    MX(S)              M(AQ)          X(AQ)
  (MOLES/LITER)          (MOLES/LITER)
 1.00000E-03    1.00000E-03    1.00000E-03
 5.00000E-03    5.00000E-03    5.00000E-03
 1.00000E-02    1.00000E-02    1.00000E-02
 1.50000E-02    1.50000E-02    1.50000E-02
 2.00000E-02    1.50000E-02    1.50000E-02
 3.00000E-02    1.50000E-02    1.50000E-02
 4.00000E-02    1.50000E-02    1.50000E-02
 5.00000E-02    1.50000E-02    1.50000E-02
 6.00000E-02    1.50000E-02    1.50000E-02
 7.00000E-02    1.50000E-02    1.50000E-02

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 +     +     +     +     +     +     +     +     +     +
                              MX(S)
```

HETERO Program

```
 10 REM                HETERØGENØUS EQUILIBRIUM SYSTEM
 20 REM WRITTEN BY JØHN MANØCK, WESTERN CARØLINA U., FØR THE
 30 REM CHEMICAL EQUILIBRIUM MØDULES. (7/75)
 40 REM ************************************************************
 50 REM THIS PRØGRAM SIMULATES A HETERØGENØUS EQUILIBRIUM SYSTEM
 60 REM WHERE THE RESULTS ARE SHØWN IN TABULAR AND GRAPHIC
 70 REM FØRMS.
 80 REM ******************** P R Ø G R A M ********************
 90 REM
100 DIM X[10],Y[10],Z[10],B$[20,3]
110 DATA .001,.001,.001,.005,.005,.005,.01,.01,.01
120 DATA .015,.015,.015,.02,.015,.015,.03,.015,.015
130 DATA .04,.015,.015,.05,.015,.015,.06,.015,.015,.07,.015,.015
140 FØR I=1 TØ 10
150   READ X[I],Y[I],Z[I]
160 NEXT I
170 PRINT "     THE FØLLØWING IS A SIMULATED SET ØF EXPERIMENTAL"
180 PRINT "RESULTS TØ ILLUSTRATE THE HETERØGENEØUS SYSTEM"
190 PRINT
200 PRINT "              MX(S)    =  M(AQ)  + X(AQ)"
210 PRINT
220 PRINT "AS IT ACHIEVES EQUILIBRIUM WITH THE ADDITIØN ØF"
230 PRINT "MØRE MX(S) TØ THE SYSTEM.  LISTED BELØW ARE"
240 PRINT "THE TABULAR RESULTS AND THE GRAPHICAL RESULTS.  HØW"
250 PRINT "WØULD YØU INTERPRET THE RESULTS FRØM YØUR KNØWLEDGE ØF"
260 PRINT "EQUILIBRIUM SYSTEMS?"
270 PRINT "    MX(S)          M(AQ)          X(AQ)"
280 PRINT "  (MØLES/LITER)      (MØLES/LITER)"
290 FØR I=1 TØ 10
300   PRINT X[I],Y[I],Z[I]
310 NEXT I
320 PRINT
330 REM
340 REM@>@> SUBRØUTINE PLØT
350 REM
360 LET Y5=.001
370 LET Y1=.019
380 LET L=10
390 FØR J=1 TØ 20
400   FØR K=2 TØ 16
410     LET B$[K]="   "
420   NEXT K
430   LET B$[1]=" I "
440   IF L=0 THEN 500
450   IF Y[L]<Y1 THEN 500
460   LET N5=X[L]*1000*(1.5/7)
470   LET B$[N5+1]=" * "
480   LET L=L-1
490   GØTØ 440
500   FØR I=1 TØ 15
510     PRINT B$[I];
520   NEXT I
530   PRINT
540   LET Y1=Y1-Y5
```

```
550 NEXT J
560 FØR J=1 TØ 15
570   PRINT " + ";
580 NEXT J
590 PRINT
600 PRINT "                          MX(S)"
610 STØP
620 END
>
```

Unit Test on Heterogeneous Ionic Equilibria

TEST 1

1. IF Cu^{+2} IS SLOWLY ADDED TO A SOLUTION 0.590 MOLAR IN S^{-2} , AT WHAT CONCENTRATION OF Cu^{+2} DOES A PRECIPITATE START TO FORM?
   THE Ksp OF CuS IS 8.00E-37 .

2. THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .
   WHAT IS THE SOLUBILITY OF $Ag_2C_2O_4$ IN WATER IN G/ML ?

3. A SOLUTION IS 0.537 M IN Cl^{-1} AND 0.6911 M IN CrO_4^{-2} .
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbCl_2$ OR $PbCrO_4$?
   THE Ksp OF $PbCl_2$ IS 1.60E-05. THE Ksp OF $PbCrO_4$ IS 2.00E-16.
   AND WHAT WILL BE THE CONCENTRATION OF THE CrO_4^{-2} ION WHEN $PbCl_2$ BEGINS TO PRECIPITATE?

4. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.202 MOLAR. IF IT IS DESIRED TO REMOVE 53.505 % OF Pb^{+2} BY ADDING S^{-2}, WHAT MUST (S^{-2}) BE?
   THE Ksp OF PbS IS 7.00E-29 .

5. IF THE Ag^{+1} CONCENTRATION IN A SOLUTION IS INITIALLY 0.804 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH $C_2O_4^{-2}$ IS ADDED TO MAKE $C_2O_4^{-2}$ CONCENTRATION 0.572 MOLAR?
   THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .
   WHAT IS THE RESULTING CONCENTRATION OF Ag^{+1} ?

6. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $PbCrO_4$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.898 MOLE/LITER OF Pb^{+2} ?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16 .

7. WHAT IS THE Ca^{+2} CONCENTRATION IN A SATURATED SOLUTION OF $CaCO_3$ IN WATER?
   THE Ksp OF $CaCO_3$ IS 2.50E-10 .

TEST 1

1. 1.36E-36 M
2. 4.26E-05
3. $PbCrO_4$ 3.60E-12
4. 7.45E-28 M
5. YES 4.39E-06 M
6. 2.23E-16
7. 1.58E-05 M

Unit Test on Heterogeneous Ionic Equilibria

TEST 2

1. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.865 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH S^{-2} IS ADDED TO MAKE S^{-2} CONCENTRATION 0.420 MOLAR?
   THE Ksp OF PbS IS 7.00E-29 .
   WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

2. IF Pb^{+2} IS SLOWLY ADDED TO A SOLUTION 0.882 MOLAR IN $C_2O_4^{-2}$, AT WHAT CONCENTRATION OF Pb^{+2} DOES A PRECIPITATE START TO FORM?
   THE Ksp OF PbC_2O_4 IS 8.30E-12 .

3. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $SrCrO_4$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.291 MOLE/LITER OF Sr^{+2} ?
   THE Ksp OF $SrCrO_4$ IS 3.60E-05 .

4. WHEN 61 ML OF 0.9101 M Sr^{+2} IS ADDED TO 39 ML OF 0.1040 M SO_4^{-2} HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF $SrSO_4$ IS 7.60E-07 .

5. A SOLUTION IS 0.789 M IN S^{-2} AND 0.2050 M IN $C_2O_4^{-2}$.
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, PbS OR PbC_2O_4 ?
   THE Ksp OF PbS IS 7.00E-29. THE Ksp OF PbC_2O_4 IS 8.30E-12.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN PbC_2O_4 BEGINS TO PRECIPITATE?

6. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF Ag_2S IN WATER?
   THE Ksp OF Ag_2S IS 5.50E-51 .

7. THE SOLUBILITY OF AgBr IN WATER IS 1.33E-04 G/L.
   CALCULATE THE Ksp OF AgBr.

TEST 2

1. YES 1.67E-28 M
2. 9.41E-12 M
3. 1.24E-04
4. 4.05E-03
5. PbS 1.73E-18
6. 2.22E-17 M
7. 5.00E-13

Unit Test on Heterogeneous Ionic Equilibria

TEST 3

1. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF PbS IN A SOLUTION THAT CONTAINS A TOTAL OF 0.219 MOLE/LITER OF Pb^{+2} ?
   THE Ksp OF PbS IS 7.00E-29 .

2. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF PbI_2 IN WATER?
   THE Ksp OF PbI_2 IS 8.30E-09 .

3. WHEN 38 ML OF 0.4311 M Ba^{+2} IS ADDED TO 62 ML OF 0.3000 M CO_3^{-2} HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF $BaCO_3$ IS 1.60E-09 .

4. THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .
   WHAT WILL THE RESULTING Ag^{+1} CONCENTRATION BE IF ENOUGH $C_2O_4^{-2}$ IS ADDED TO A SATURATED SOLUTION OF $Ag_2C_2O_4$ TO MAKE ($C_2O_4^{-2}$) 0.471 MOLAR?

5. A SOLUTION IS 0.920 M IN CO_3^{-2} AND 0.3300 M IN S^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, Ag_2CO_3 OR Ag_2S ?
   THE Ksp OF Ag_2CO_3 IS 8.20E-12. THE Ksp OF Ag_2S IS 6.50E-51.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN Ag_2CO_3 BEGINS TO PRECIPITATE?

6. IF Co^{+2} IS SLOWLY ADDED TO A SOLUTION 0.432 MOLAR IN S^{-2} , AT WHAT CONCENTRATION OF Co^{+2} DOES A PRECIPITATE START TO FORM?
   THE Ksp OF CoS IS 5.00E-22 .

7. THE Ksp OF SrF_2 IS 7.90E-10 .
   WHAT IS THE SOLUBILITY OF SrF_2 IN WATER IN G/ML ?

TEST 3

1. 3.20E-28
2. 1.28E-03 M
3. 1.64E-02
4. 4.83E-06 M
5. Ag_2S 6.17E-40
6. 1.16E-21 M
7. 7.31E-05

Unit Test on Heterogeneous Ionic Equilibria

TEST 4

1. WHEN 53 ML OF 0.7541 M Pb^{+2} IS ADDED TO 47 ML OF 0.4180 M CrO_4^{-2} HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16 .

2. THE Ksp OF AgI IS 8.50E-17 .
   WHAT IS THE SOLUBILITY OF AgI IN WATER IN G/ML ?

3. THE Ksp OF Ag_2CrO_4 IS 1.90E-12 .
   WHAT WILL THE RESULTING Ag^{+1} CONCENTRATION BE IF ENOUGH CrO_4^{-2} IS ADDED TO A SATURATED SOLUTION OF Ag_2CrO_4 TO MAKE (CrO_4^{-2}) 0.596 MOLAR?

4. IF Ag^{+1} IS SLOWLY ADDED TO A SOLUTION 0.984 MOLAR IN Br^{-1} , AT WHAT CONCENTRATION OF Ag^{+1} DOES A PRECIPITATE START TO FORM?
   THE Ksp OF AgBr IS 5.00E-13 .

5. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF AgBr IN WATER?
   THE Ksp OF AgBr IS 5.00E-13 .

6. A SOLUTION IS 0.308 M IN SO_4^{-2} AND 0.0141 M IN Br^{-1} . IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbSO_4$ OR $PbBr_2$?
   THE Ksp OF $PbSO_4$ IS 1.30E-08. THE Ksp OF $PbBr_2$ IS 4.60E-06. AND WHAT WILL BE THE CONCENTRATION OF THE SO_4^{-2} ION WHEN $PbBr_2$ BEGINS TO PRECIPITATE?

7. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $SrCrO_4$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.580 MOLE/LITER OF Sr^{+2} ?
   THE Ksp OF $SrCrO_4$ IS 3.60E-05 .

TEST 4

1. 1.96E-02
2. 2.16E-09
3. 1.79E-06 M
4. 5.08E-13 M
5. 7.07E-07 M
6. $PbSO_4$ 5.58E-07
7. 6.21E-05

Unit Test on Heterogeneous Ionic Equilibria

TEST 5

1. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.845 MOLAR. IF IT IS DESIRED TO REMOVE 43.506 % OF Pb^{+2} BY ADDING S^{-2}, WHAT MUST (S^{-2}) BE? THE Ksp OF PbS IS 7.00E-29 .

2. IF Ba^{+2} IS SLOWLY ADDED TO A SOLUTION 0.429 MOLAR IN SO_4^{-2}, AT WHAT CONCENTRATION OF Ba^{+2} DOES A PRECIPITATE START TO FORM? THE Ksp OF $BaSO_4$ IS 1.50E-09 .

3. THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 . WHAT IS THE SOLUBILITY OF $Ag_2C_2O_4$ IN WATER IN G/ML ?

4. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF Ag_2CrO_4 IN WATER? THE Ksp OF Ag_2CrO_4 IS 1.90E-12 .

5. THE Ksp OF $PbCl_2$ IS 1.60E-05 . WHAT WILL THE RESULTING Pb^{+2} CONCENTRATION BE IF ENOUGH Cl^{-1} IS ADDED TO A SATURATED SOLUTION OF $PbCl_2$ TO MAKE (Cl^{-1}) 0.862 MOLAR?

6. IF THE Sr^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.332 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH F^{-1} IS ADDED TO MAKE F^{-1} CONCENTRATION 0.650 MOLAR? THE Ksp OF SrF_2 IS 7.90E-10 . WHAT IS THE RESULTING CONCENTRATION OF Sr^{+2} ?

7. A SOLUTION IS 0.774 M IN CrO_4^{-2} AND 0.9361 M IN I^{-1} . IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbCrO_4$ OR PbI_2 ? THE Ksp OF $PbCrO_4$ IS 2.00E-16. THE Ksp OF PbI_2 IS 8.30E-09. AND WHAT WILL BE THE CONCENTRATION OF THE CrO_4^{-2} ION WHEN PbI_2 BEGINS TO PRECIPITATE?

TEST 5

1. 1.47E-28 M
2. 3.50E-09 M
3. 4.26E-05
4. 1.56E-04 M
5. 2.15E-05 M
6. YES 1.87E-09 M
7. $PbCrO_4$ 2.11E-08

TEST 6

1. THE Ksp OF PbS IS 7.00E-29 .
   WHAT WILL THE RESULTING Pb^{+2} CONCENTRATION BE IF ENOUGH S^{-2} IS ADDED TO A SATURATED SOLUTION OF PbS TO MAKE (S^{-2}) 0.907 MOLAR?

2. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF AgBr IN A SOLUTION THAT CONTAINS A TOTAL OF 0.863 MOLE/LITER OF Ag^{+1} ?
   THE Ksp OF AgBr IS 5.00E-13 .

3. THE Ksp OF $PbCO_3$ IS 1.50E-15 .
   WHAT IS THE SOLUBILITY OF $PbCO_3$ IN WATER IN G/ML ?

4. A SOLUTION IS 0.244 M IN S^{-2} AND 0.7751 M IN SO_4^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, Ag_2S OR Ag_2SO_4 ?
   THE Ksp OF Ag_2S IS 5.50E-51. THE Ksp OF Ag_2SO_4 IS 1.20E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE S^{-2} ION WHEN Ag_2SO_4 BEGINS TO PRECIPITATE?

5. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.446 MOLAR. IF IT IS DESIRED TO REMOVE 10.106 % OF Pb^{+2} BY ADDING CO_3^{-2}, WHAT MUST (CO_3^{-2}) BE?
   THE Ksp OF $PbCO_3$ IS 1.50E-15 .

6. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF PbI_2 IN WATER?
   THE Ksp OF PbI_2 IS 8.30E-09 .

7. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.294 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH CrO_4^{-2} IS ADDED TO MAKE CrO_4^{-2} CONCENTRATION 0.963 MOLAR?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16 .
   WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

TEST 6

1. 7.72E-29 M
2. 5.79E-13
3. 1.03E-08
4. Ag_2S 3.55E-46
5. 3.74E-15 M
6. 1.28E-03 M
7. YES 2.08E-16 M

Unit Test on Heterogeneous Ionic Equilibria

TEST 7

1. A SOLUTION IS 0.885 M IN CO_3^{-2} AND 0.0540 M IN SO_4^{-2} .
   IF SOLID Pb(NO3)2 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $PbCO_3$ OR $PbSO_4$?
   THE Ksp OF $PbCO_3$ IS 1.50E-15. THE Ksp OF $PbSO_4$ IS 1.30E-08.
   AND WHAT WILL BE THE CONCENTRATION OF THE CO_3^{-2} ION WHEN $PbSO_4$
   BEGINS TO PRECIPITATE?

2. THE Ksp OF Ag_2CO_3 IS 8.20E-12 .
   WHAT IS THE SOLUBILITY OF Ag_2CO_3 IN WATER IN G/ML ?

3. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $PbCrO_4$ IN
   A SOLUTION THAT CONTAINS A TOTAL OF 0.747 MOLE/LITER OF
   Pb^{+2} ?
   THE Ksp OF $PbCrO_4$ IS 2.00E-16 .

4. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF
   AgI IN WATER?
   THE Ksp OF AgI IS 8.50E-17 .

5. IF THE Pb^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY
   0.281 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH Cl^{-1} IS ADDED
   TO MAKE Cl^{-1} CONCENTRATION 0.887 MOLAR?
   THE Ksp OF $PbCl_2$ IS 1.60E-05 .
   WHAT IS THE RESULTING CONCENTRATION OF Pb^{+2} ?

6. WHEN 78 ML OF 0.1671 M Ag^{+1} IS ADDED TO 22 ML OF 0.6060 M I^{-1}
   HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF AgI IS 8.50E-17 .

7. IF Ag^{+1} IS SLOWLY ADDED TO A SOLUTION
   0.261 MOLAR IN I^{-1} , AT WHAT CONCENTRATION OF Ag^{+1}
   DOES A PRECIPITATE START TO FORM?
   THE Ksp OF AgI IS 8.50E-17 .

TEST 7

1. $PbCO_3$ 6.24E-09
2. 3.50E-05
3. 2.68E-16
4. 9.22E-09 M
5. YES 2.03E-05 M
6. 1.30E-02
7. 3.26E-16 M

Unit Test on Heterogeneous Ionic Equilibria

TEST 8

1. THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .
   WHAT IS THE SOLUBILITY OF $Ag_2C_2O_4$ IN WATER IN G/ML ?

2. A SOLUTION IS 0.612 M IN $C_2O_4^{-2}$ AND 0.7971 M IN CO_3^{-2} .
   IF SOLID AgNO3 IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $Ag_2C_2O_4$ OR Ag_2CO_3 ?
   THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11. THE Ksp OF Ag_2CO_3 IS 8.20E-12.
   AND WHAT WILL BE THE CONCENTRATION OF THE CO_3^{-2} ION WHEN $Ag_2C_2O_4$
   BEGINS TO PRECIPITATE?

3. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Ag^{+1} IS 0.362 MOLAR.
   IF IT IS DESIRED TO REMOVE 89.206 % OF Ag^{+1}
   BY ADDING I^{-1}, WHAT MUST (I^{-1}) BE?
   THE Ksp OF AgI IS 8.50E-17 .

4. IF THE Co^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY
   0.488 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH S^{-2} IS ADDED
   TO MAKE S^{-2} CONCENTRATION 0.729 MOLAR?
   THE Ksp OF CoS IS 5.00E-22 .
   WHAT IS THE RESULTING CONCENTRATION OF Co^{+2} ?

5. THE Ksp OF $BaCrO_4$ IS 8.50E-11 .
   WHAT WILL THE RESULTING Ba^{+2} CONCENTRATION BE IF ENOUGH
   CrO_4^{-2} IS ADDED TO A SATURATED SOLUTION OF $BaCrO_4$
   TO MAKE (CrO_4^{-2}) 0.199 MOLAR?

6. IF Hg^{+2} IS SLOWLY ADDED TO A SOLUTION
   0.255 MOLAR IN S^{-2} , AT WHAT CONCENTRATION OF Hg^{+2}
   DOES A PRECIPITATE START TO FORM?
   THE Ksp OF HgS IS 1.60E-54 .

7. WHAT IS THE Ag^{+1} CONCENTRATION IN A SATURATED SOLUTION OF
   $Ag_2C_2O_4$ IN WATER?
   THE Ksp OF $Ag_2C_2O_4$ IS 1.10E-11 .

TEST 8

1. 4.26E-05
2. Ag_2CO_3 4.56E-01
3. 2.18E-15 M
4. YES 6.86E-22 M
5. 4.27E-10 M
6. 6.28E-54 M
7. 2.80E-04 M

Unit Test on Heterogeneous Ionic Equilibria

TEST 9

1. THE SOLUBILITY OF Ag_2CO_3 IN WATER IS 3.50E-02 G/L.
   CALCULATE THE Ksp OF Ag_2CO_3.

2. GIVEN A SOLUTION IN WHICH THE CONCENTRATION OF Pb^{+2} IS 0.630 MOLAR.
   IF IT IS DESIRED TO REMOVE 45.805 % OF Pb^{+2}
   BY ADDING Br^{-1}, WHAT MUST (Br^{-1}) BE?
   THE Ksp OF $PbBr_2$ IS 4.60E-06 .

3. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $PbCl_2$ IN
   A SOLUTION THAT CONTAINS A TOTAL OF 0.084 MOLE/LITER OF
   Pb^{+2} ?
   THE Ksp OF $PbCl_2$ IS 1.60E-05 .

4. IF Co^{+2} IS SLOWLY ADDED TO A SOLUTION
   0.507 MOLAR IN S^{-2} , AT WHAT CONCENTRATION OF Co^{+2}
   DOES A PRECIPITATE START TO FORM?
   THE Ksp OF CoS IS 5.00E-22 .

5. THE Ksp OF CoS IS 5.00E-22 .
   WHAT WILL THE RESULTING Co^{+2} CONCENTRATION BE IF ENOUGH
   S^{-2} IS ADDED TO A SATURATED SOLUTION OF CoS
   TO MAKE (S^{-2}) 0.773 MOLAR?

6. WHAT IS THE Pb^{+2} CONCENTRATION IN A SATURATED SOLUTION OF
   PbS IN WATER?
   THE Ksp OF PbS IS 7.00E-29 .

7. A SOLUTION IS 0.484 M IN CO_3^{-2} AND 0.0930 M IN SO_4^{-2} .
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH
   WILL PRECIPITATE FIRST, $PbCO_3$ OR $PbSO_4$?
   THE Ksp OF $PbCO_3$ IS 1.50E-15. THE Ksp OF $PbSO_4$ IS 1.30E-08.
   AND WHAT WILL BE THE CONCENTRATION OF THE CO_3^{-2} ION WHEN $PbSO_4$
   BEGINS TO PRECIPITATE?

TEST 9

1. 8.20E-12
2. 3.67E-03 M
3. 6.90E-03
4. 9.86E-22 M
5. 6.47E-22 M
6. 8.37E-15 M
7. $PbCO_3$ 1.07E-08

TEST 10

1. A SOLUTION IS 0.293 M IN Br^{-1} AND 0.2971 M IN Cl^{-1} .
   IF SOLID $Pb(NO3)2$ IS GRADUALLY ADDED TO THIS SOLUTION, WHICH WILL PRECIPITATE FIRST, $PbBr_2$ OR $PbCl_2$?
   THE Ksp OF $PbBr_2$ IS 4.60E-06. THE Ksp OF $PbCl_2$ IS 1.60E-05.
   AND WHAT WILL BE THE CONCENTRATION OF THE Br^{-1} ION WHEN $PbCl_2$ BEGINS TO PRECIPITATE?

2. THE SOLUBILITY OF Ag_2CO_3 IN WATER IS 3.50E-02 G/L.
   CALCULATE THE Ksp OF Ag_2CO_3.

3. WHAT IS THE Ba^{+2} CONCENTRATION IN A SATURATED SOLUTION OF $BaCO_3$ IN WATER?
   THE Ksp OF $BaCO_3$ IS 1.60E-09 .

4. IF THE Sr^{+2} CONCENTRATION IN A SOLUTION IS INITIALLY 0.299 MOLAR, WILL A PRECIPITATE FORM IF ENOUGH CrO_4^{-2} IS ADDED TO MAKE CrO_4^{-2} CONCENTRATION 0.628 MOLAR?
   THE Ksp OF $SrCrO_4$ IS 3.60E-05 .
   WHAT IS THE RESULTING CONCENTRATION OF Sr^{+2} ?

5. THE Ksp OF PbS IS 7.00E-29 .
   WHAT WILL THE RESULTING Pb^{+2} CONCENTRATION BE IF ENOUGH S^{-2} IS ADDED TO A SATURATED SOLUTION OF PbS TO MAKE (S^{-2}) 0.780 MOLAR?

6. WHEN 66 ML OF 0.7050 M Hg^{+2} IS ADDED TO 34 ML OF 0.4210 M S^{-2} HOW MANY MOLES OF PRECIPITATE IS FORMED, IF ANY?
   THE Ksp OF HgS IS 1.60E-54 .

7. WHAT IS THE SOLUBILITY, IN MOLES PER LITER OF $BaCrO_4$ IN A SOLUTION THAT CONTAINS A TOTAL OF 0.655 MOLE/LITER OF Ba^{+2} ?
   THE Ksp OF $BaCrO_4$ IS 8.50E-11 .

TEST 10

1. $PbBr_2$ 1.59E-01
2. 8.20E-12
3. 4.00E-05 M
4. YES 5.73E-05 M
5. 8.97E-29 M
6. 1.43E-02
7. 1.30E-10